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THE UNIVERSITY OF HULL

Department of Engineering

Third Year Laboratory

Module 13511

Lab Experiment: Signals, Systems and Spectrum Analysis

All Lab reports are to be submitted on time otherwise a penalty according to university rules will be applied. It is understood that you have read and understood the university regulations regarding plagiarism

Purpose

This Laboratory exercise aims at introducing you to some key concepts in signal spectrum analysis. The laboratory experiment guides you on how to use to the spectrum analyzer and will display the importance of its usage while designing communication systems. This experiment does not require any prior experience with the spectrum analyzer but it is recommended that you should revise your course notes of *Radio Systems Engineering I and Radio Spectrum Management* to have a better understanding of some concepts explained in the notes. If you are the first or second group to do this experiment you may not have the course notes at the moment but you can read them later on and relate the concepts learned here and in your notes.

You are required to do this experiment as a group but it is emphasized that every one of you should try to do a part of this experiment in order to learn the use of spectrum analyzer which is a fundamental test and measurement equipment in the field of RF Communications. Any difficulty experience should be reported to the Lab Instructor.

Objectives

At the end of this Lab you must be able to

1. Understand the importance of Frequency Domain Analysis
2. Know how to use the Spectrum Analyzer
3. Limitations of the measurement accuracy
4. Explain spurious signals, noise and concepts of AM and FM modulation

Equipment Required

1. **Signal Generator :** *Hewlett Packard 8648B*
2. **Spectrum Analyzer:** *Anritsu MS 2601 x*
3.

Instructions:

1. **Please switch on the Spectrum Analyzer MS2601 before you proceed with the Pre-Lab study. Spectrum analyzer requires a warm up time for higher accuracy.**

2. **All parts of this Laboratory Experiment should be completed on this Lab sheet provided**

3. **There are some parts which require individual study and it is not required to share the results for those parts.**

Pre-Experiment Study

Most of you with some electronics background must be familiar with the equipment called Oscilloscope and so you must know that Oscilloscope is the receiver for time domain like wise Spectrum Analyzer is the receiver of choice for the frequency domain analysis. See Figure 1 for understanding.

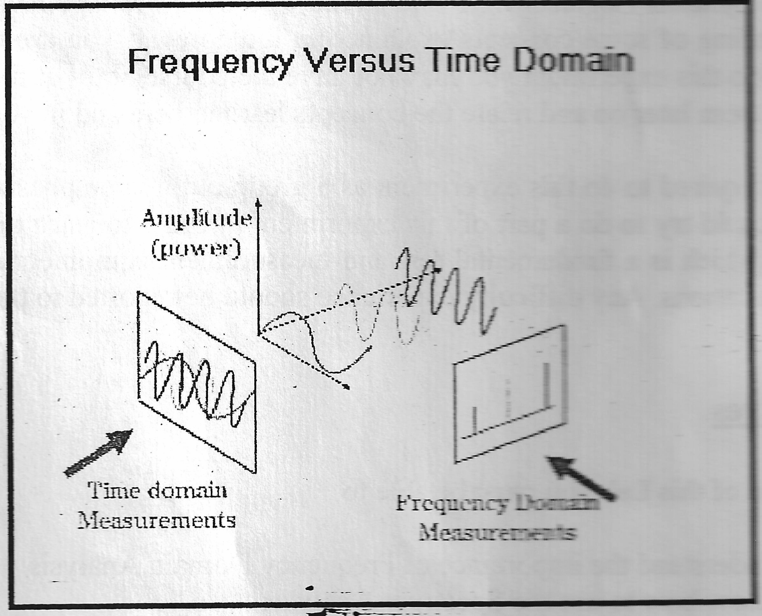


Figure 1

In the time domain all frequency components are usually summed up and then displayed whereas in case of frequency domain signals are separated into their frequency components and the level at each frequency is displayed. Frequency domain analysis is clearly very important for systems in which users are assigned different frequencies to transmit and receive and it is required that a check should be made that no one is interfering with neighboring frequencies. Examples of such

systems can be Frequency Division Multiple Access (FDMA) or Frequency Division Multiplexing (FDM) based systems like Advanced Mobile Phone Service (AMPS).

It is also to be noted that signals have specific characteristics based on the modulation scheme used to modulate them in order to transmit them. Measuring the quality of modulation is important for making sure that the system is working properly. Due to the reasons of scarcity the available bandwidth is always limited and so it is fundamental for spectrum management reasons that spectral content is understood. Distortion is another very important thing to be kept in mind while designing a system as excessive harmonic distortion at the output of a transmitter can interfere with other communication bands (must refer to *Radio Systems Engineering I* Course notes to see that pre-amplification stages in a receiver must be free of inter modulation distortion to prevent cross talk). Noise is another very important factor that needs to be taken into consideration before designing a system. Signal to Noise Ratio (SNR) measurements are fundamental in characterizing the performance of a device/system.

All these measurements that are mentioned in the paragraph above can be made in the frequency domain with the help of Spectrum Analyzer. During this experiment you will be making use of Spectrum Analyzer to measure distortion, noise and modulation.

The RF characteristics of the spectrum analyzer limit its frequency resolution and contribute to the broad frequency response that you will see in the later part of the lab. This broad frequency response is usually the analyzer's tracing of its own Resolution bandwidth (IF filter) shape. The factors which limit the frequency resolution of the spectrum analyzer are

1. Resolution Filter Bandwidth
2. Shape Factor of IF filter
3. Local Oscillator Residual FM
4. Noise Sidebands

The resolution bandwidth of plays a very important role when resolving two equal amplitude signals. The 3dB bandwidth tells us how close together equal amplitude signals can be and still be distinguished.

Now you will be using the concepts learned in this section for doing the empirical work and will also require answering few questions based on these concepts.

Lab Procedure

You will begin the experiment by setting up the equipment and then measuring simple known signals.

1. Find the RF output on the Signal Generator which is on the Bottom Right of the front panel of the 8648 B.

2. Take a BNC cable and connect one end to the RF output of the Signa Generator

3. Locate the RF Input on the MS2601 which is on the Bottom Left of the fron panel.

4. Connect the second end of BNC cable such that Signal Generator's output i connected to the input of Spectrum Analyzer.

Now follow the Keystrokes and remember the functions that each key strok performs.

Instructions and [Keystrokes]

1. Switch on the 8648 B **[Power]**
2. Select output Frequency 300MHz **[Frequency] [300** **[MHz]**
3. Select output signal Level Amplitude 0 dBm **[Amplitude] [0] [dBm]**
4. Switch off modulation **[Mod ON/OFF]**
5. Enable RF output **[RF ON/OFF]**

Now Set up Spectrum Analyzer

Instructions and [Keystrokes]

1. Return MS2601 to a known state **[Initial]**
2. Select Frequency Rang to Display
   Set start frequency **[Shift] [center] [250** **[MHz]**
   Set stop frequency **[Shift] [Span] [350**
[MHz]
3. Adjust Vertical Display dB/division 10dB/ division **[Shift] [8] [F1 to F6]**
4. Use MS2601 Internal frequency Counter for higher Accuracy **[Shift] [1]**
5. Set Resolution to 1Hz **[F2] to select**
6. Set count on **[F1]**

Read the Frequency and Amplitude of the Signal Under Test.

299.999 650
~~300MHz~~ MHz −0.6~~8~~7
dBm

Explain in the space provided below the reasons for which there is a difference in values measured by the spectrum analyzer and the one displayed by the signal generator

- Cable antenuation (Bandwith limitation)
- Internal noise of spectrum analyzer
- Internal oscillator residual Frequency Modulation
- Internal clock offset

Estimate the Cable Loss

-0.67 **dBm**

Calculate the Frequency Error in PPM (Parts per Million)

$$\frac{\textbf{Frequency offset (Hz)}}{\textbf{Carrier frequency (Hz)}} \times 10^6$$

1.17 ~~[illegible]~~ **PPM**

Instruction

Now connect the 10 MHz reference output of the Signal Generator at the back of 8468 B to the 10 MHz reference input at the back of MS 2601.

Repeat the Instructions of setup and record the frequency and the amplitude of the signal under test

299 999 990 Hz / -0.67 dBm

MHz ____ −0.67 ____ dBm

Recalculate the Frequency Error in PPM

0.03(3) PPM

What does the difference in the error suggest?

Synchronised clock signal between receiver and transmitter improve ~~spectrum to~~ signal detection and processing (FFT)

Given that the signal generator is giving out an unmodulated 300 MHz signal, why is the spectrum analyzer displaying a response other than a vertical frequency impulse response at 300 MHz?

Because of internal noise produced by receiver, mainly due to modulation products produced by IF filters. Spectrum analyzer mixes input signals with many frequencies producing noise at the early stage of detection.

Now you will vary the Resolution Bandwidth of the MS2601 and notice the change in the shape of the signal

Instructions and [Keystrokes]

1. Vary Resolution filter 3 dB B.W **[Resoln BW] [F5 and F6]**

Change to 1 MHz, 10 KHz and 1 KHz Observe the signal at each change.

What Change is noticed and why?

1kHz / Frequency offset is 11Hz / −1.13 dBm, pulse at 300MHz is very narrow (< 15kHz in width), noise not present. 10kHz, pulse width (~~8kHz~~ 160kHz) −0.78 dBm. F0 is the same. Noise levels go up with frequency increase. 100kHz −0.69 dBm, 1.44MHz pulse width. There is resolution vs power tradeoff. 1MHz −0.88 dBm, 4MHz pulse width.

Repeat the procedure above. Notice and record the change in sweep time associated with each resolution bandwidth.

250MHz → 350 MHz

1 MHz	50	**ms**
100 KHz	50	**ms**
10 KHz	3	**s**
1 KHz	300	**s**

Increased resolution detects pulse better and filters out noise better at the cost of losing transmitted power (pulse peak). Reason more filters at more precise frequencies are used for detection.

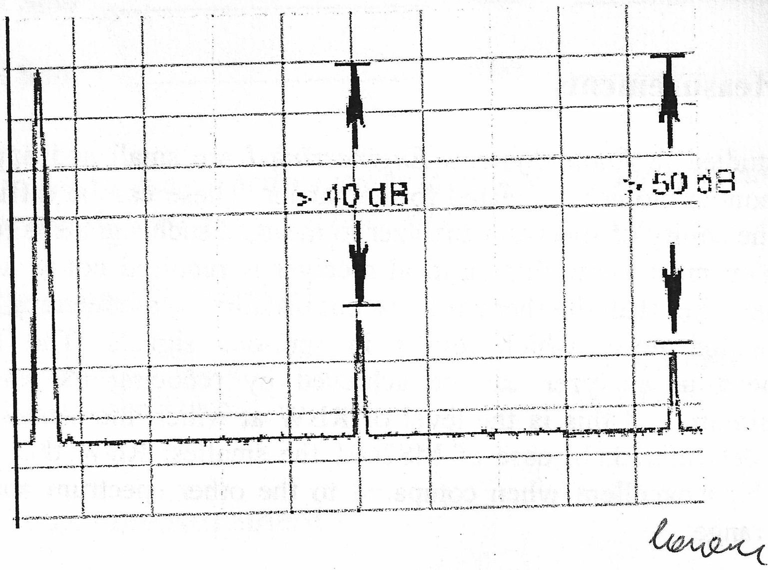
Instruction

Set resolution bandwidth back to 100 KHz

After doing this part of the experiment and learned the concepts explained in the pre-experiment study determine the minimum resolution bandwidth required to distinguish between two equal amplitude signals 300 Hz apart

You have already learned and experienced the importance of IF filter in limiting the Resolution bandwidth please learn at home and write about the importance and effects of other factors limiting the Resolution bandwidth. Use the space below.

Harmonic Distortion Measurements



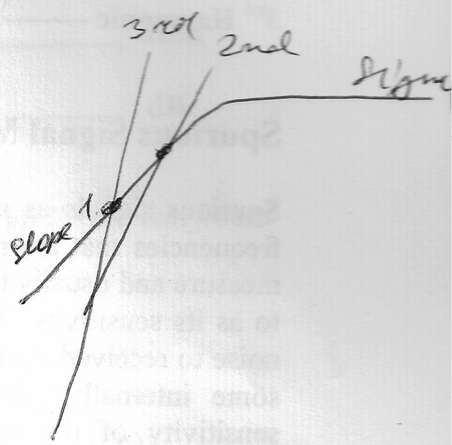


Figure 2

Now you will setup to measure the second and third harmonic distortion products.

Instructions and [Keystrokes]

1. Increase the Stop Frequency **[Shift] [Span] [1000] [MHz]**
   So that 2^{nd} and 3^{rd} harmonic of the signal can be viewed
2. Set Marker for peak search **[Marker] [F3]**

Frequency of fundamental signal 299 999 990 **MHz**

Amplitude of fundamental signal -0.68 **dBm**

3. Set fundamental as Reference **[F2]**
4. Select Marker 2 **[F6]**
5. Select delta function **[F2]**
6. Rotate the knob on the top right hand of MS2601 to read the amplitude in dB below carrier for 2^{nd} and third harmonic or follow step 7 and step 8
7. Select Marker 1 again **[F6]**
8. Use Next peak Function to read 2^{nd} and 3^{rd} harmonic **[F3]**

Record frequency in MHz and relative amplitude

2^{nd} Harmonic 600 **MHz** -57 **dBc**

3rd Harmonic ___900___ MHz ___-52___ dBc

Spurious Signal Measurements

Spurious signals as studied in *Radio Systems Engineering I* are small and appea frequencies that are non-harmonically related to the carrier. These can be difficul measure and usually the ability of spectrum analyzer to measure such signals is refe to as its sensitivity. You must know that an ideal receiver is required not to add noise to received signal other than the thermal noise but usually in practice they do some internally generated noise which results in spurious signals. The hig sensitivity of the spectrum analyzer can be achieved by reducing its resolu bandwidth to the minimum and this is the level of RBW at which the sensitivit spectrum analyzer is determined. In case of MS2601 the smallest RBW that car achieved is 30 Hz which excellent when compared to the other spectrum analy available in this price range.

In this part you will setup the spectrum analyzer to measure the value of the lar spurious signal.

Instructions and [Keystrokes]

1. Set MS2601 frequency range
   Start frequency 50 MHz
   Stop frequency 2200 MHz
2. Resolution bandwidth 1 MHz
3. Find and Record fundamental

ALL KEY STRO REQUIRED FOR THIS PART HAVE BE TAUGHT IN EARL SECTIONS

Fundamental ___299 999 990___ **MHz** ___-1.05___ **dBm**

Is there a spur easily detectable? ________

If not explain why?

____

____

____

____

(If anyone in your lab group does not know why don't share the results o following question)

Measure and Record Value of Largest Spur

$nf_1 \pm mf_2$

$n, m, 1, 2, 3$

28 November

Largest Spur ________________ **MHz** ________________ **dBm**

Largest Spur ________________ **MHz** ________________ **dBc**

Hint: *In order to have a better reading after detecting the spur carefully you can freeze the trace and then use marker to read values*

Instructions and [Keystrokes]

1. To choose the Trace **[Shift] [4]**
2. To freeze the Trace **[F1]**

Phase Noise measurement

Before you configure spectrum analyzer to measure phase noise of the signal you must remember these measurement fundamentals

1. Signals below the noise sidebands of the spectrum analyzer cannot be detected

2. Phase noise is measured relative to the carrier level at a specific offset and referenced to a specific noise bandwidth (e.g. 1Hz)

3. Noise is random and therefore its accurate measurement requires sampling detection technique

Now configure spectrum analyzer and signal generator

Instructions and [Keystrokes]

For Signal Generator

1. Select output frequency as 860 MHz
2. Amplitude 0 dBm
3. Modulation OFF
4. Enable RF

For Spectrum Analyzer

1. Return MS 2601 to a known state
2. Select Center frequency **[Center] [860] [MHz]**
3. Set the Span **[Span] [30] [KHz]**
4. Adjust RBW to 1KHz
5. Set Marker, first search peak then set its as reference
   Then choose delta function
6. To Read values accurately select Z Width to Dip.N **[F4]**
7. Rotate Knob on Right side of MS2601 to move 10 KHz

Now read the phase noise at 10 KHz Offset -75 **dBc**

Now press [F4} again to change Z Width NAR and see the difference in Value.

-65 dBc

Modulation Measurements

Amplitude Modulation

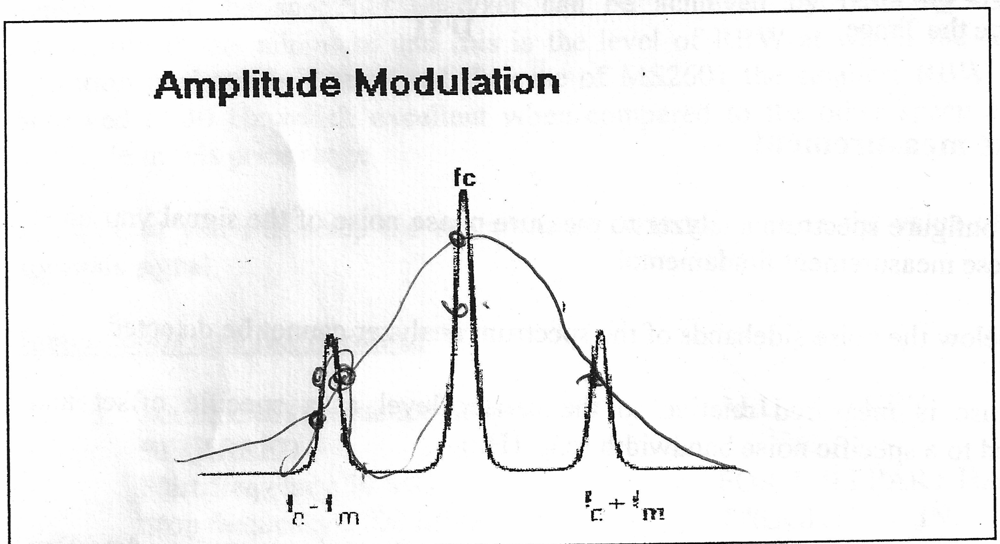


Figure 3

Amplitude modulation occurs when a modulating signal causes an amplitude varia in a given signal without changing either phase or frequency. The variation in amplitude is proportional to the instantaneous amplitude of the modulating si whereas the rate of deviation is proportional to the frequency of the modulating sig By letting the modulating waveform be represented as COS ($\omega_m t$) we can describe signal in the frequency domain as three Sine waves.

$$V(t) = [1+m \times \cos(\omega_m t)] \times \cos(\omega_c t) = \cos(\omega_c t) + m/2 \times \cos[(\omega_c - \omega_m) \times t] + m$$
$$\cos[(\omega_c + \omega_m) \times t]$$

$$m = \text{modulation index} = 2 \times V_{sideband} / V\ \text{carrier}$$

The purpose of this part of the lab is to familiarize you with the signal genera modulation generation and the spectrum analyzer's modulation analysis capab This part of experiment is aimed at covering the AM modulation and analysis

Instructions and [Keystrokes]

For setting up signal generator

1. Select and output frequency of 300 KHz
2. Set the amplitude as -10 dBm
3. configure modulation as AM and modulation depth as 10 % **[AM] [10] [%]**
4. Set modulation Rate as 1 KHz **[INT 1 KHz]**
5. Enable Modulation **[Mod ON/OFF]**
6. Enable RF

For setting up Spectrum Analyzer

1. Return MS2601 to a know state
2. Select frequency range Center at 300 KHz and Span as 10 KHz
3. Select Resolution BW as 300 Hz
4. Set marker for Values in reference with carrier
5. Measure and record 1KHz AM Sideband

Value at 301 KHz **Delta dB** -25 **dBc**

Calculate the % AM associated with the dBc value that you read on the spectrum analyzer using the following formula

%AM Modulation Index = m= 2 x 10 ^ (delta dB/20) x 100 %

%AM Modulation Index =m = 11

Reconfigure Signal Generator modulation output to 400 Hz **[INT 400 HZ]**

Remeasure and recalculate the signal's %AM for the new signal

+40 Hz

At 300.04 kHz **Delta dB** -26 **dBc**

% AM Modulation Index =m= 10

Does this value agree with the value on the signal generator if not why?

Yes, it does. ~1% is due to cable and internal noise

Hint: resolution bandwidth set is 300Hz

Now you will learn to use spectrum analyzer to analyze the AM modulation in time domain. You must be able to deduce using knowledge gained from previ parts of this lab that in order to be in the time domain the resolution bandwidth of instrument must be wider than the spectral components.

As mentioned in the earlier part of this lab report spectrum analyzer can also be u for time domain measurements and this is possible by setting the span of the spectr analyzer to a value of zero. The sweep time is non zero, center frequency is se carrier frequency and the resolution bandwidth must be large enough to incl modulation sidebands in the measurement. It must be remembered that the spect analyzer does not show the negative values of the amplitude. Also due to the us envelope detectors the spectrum analyzer strips off the carrier and therefore only baseband modulating signal can be seen. See Figure 4

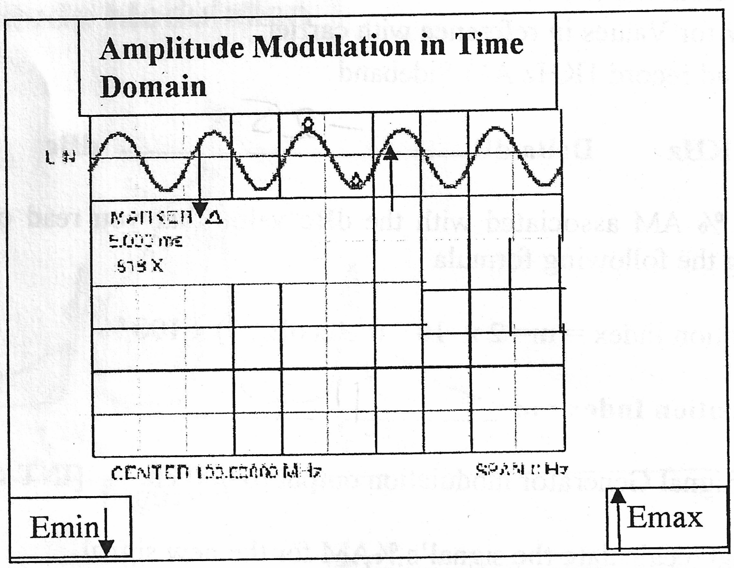


Figure 4

The formula to calculate the AM modulation index in the time domain is as g below

$$m = \frac{Emax - Emin}{Emax + Emin}$$

Using this formula you will be required to calculate the m in the next part.

Instructions and [Keystrokes]

Setup for Signal Generator

1. Select output frequency as 400 MHz

2. Select output signal level as –10 dBm
3. Set AM Modulation depth as 30 %
4. Set AM rate as 400 Hz
5. Enable RF output

Setup for Spectrum Analyzer

1. Return to a known state
2. Set center frequency as 400 MHz
3. Set span to 0
4. Set Scale to LIN **[shift] [8] [F1 to F6]**
5. Select Resolution bandwidth as 1KHz
6. Set Sweep time as 50 msec **[Sweep time][F5 to F6]**
7. Freeze the trace
8. Set marker delta
9. Read and Record Values

Emax 60 mV

Emin 35 mV

% AM 26 %

Narrowband Frequency Modulation

FM consists of infinite number of sidebands however in case of narrowband FM there are two significant sidebands. The amplitude of these sidebands relative to the amplitude of the carrier is given by the formula given below

$$dBc = 20 \log (b/2)$$

$$b = \text{modulation index} = 2 \times 10^{(dBc/20)}$$

Instructions and [Keystrokes]

Setup Signal Generator

1. Set output as 100 MHz
2. Set amplitude as –10 dBm
3. Configure FM output [FM] [0.10] [KHz]
4. Set modulation On
5. Enable RF

mod. 1kHz.

Setup for MS2601

1. Initialize
2. Set center frequency as 100 MHz
3. Set span as 50 KHz
4. Set Resolution BW as 100 Hz
5. Set Marker to Peak Search
6. Marker Delta
7. and now read and record values in dBc for sidebands

Sideband Level -26 **dBc**

Calculate b = 0.1

This brings you to the end of this Laboratory Experiment. Make sure tha equipment is switched off and BNC Cables detached and kept away safely.

In addition to this you must write a note describing the importance of function of spectrum analyzer that has been used in this laboratory exercise also write detailed notes about AM modulation, FM modulation and p modulation. You are also required to read and comment on the latest modula schemes and their associated baud rates such as Quadrature Phase shift key Binary Phase shift keying, Quadrature Amplitude modulation. Attach this as separate sheets of paper.

References

1. Anritsu, Spectrum Analyzer MS2601 Operation Manual
2. Hewlett- Packard Company, Spectrum Analysis Basics, Application Note (HP publication number 5952-0292, November 1, 1989)

3. Hewlett-Packard company, 8 Hints to Better Spectrum Analyzer Measurements, (HP publication number 5965-6854E, December 1996)

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